Report for 2001ME2281B: Seepage Lakes as Indicators of Climate Change: Is Maine Really Cooling?

- Conference Proceedings:
  - Seger, E., K. Webster, J. Kahl. 2001. Chemical Responses to Drought: Comparison of Acid-Sensitive Seepage Lakes in Maine and Wisconsin. Poster presentation at the 4th Annual Association of Graduate Students Graduate Research Exposition, April 2002, University of Maine, Orono, Maine.
  - Seger, E., K. Webster, J. Kahl. 2001. Chemical Responses to Drought: Comparison of Acid-Sensitive Seepage Lakes in Maine and Wisconsin. Poster presentation at the Maine Water Conference, May 2002, Augusta, Maine. (Award for Best Student Poster)
- Other Publications:
  - Seger, E., K. Webster, J. Kahl. 2001. Chemical Responses to Drought: Comparison of Acid-Sensitive Seepage Lakes in Maine and Wisconsin. Poster presentation at the American Society of Limnology and Oceanography Conference, June 2002, Victoria, British Columbia.

Report Follows:

Seepage Lakes as Indicators of Climate Change

Katherine E. Webster, Jeffrey S. Kahl
University of Maine

Problem and Research Objectives:

Although evidence suggests that the global climate is warming, much uncertainty exists in predictions of local changes in climate, including the seasonality, direction and magnitude of changes in precipitation and temperature. As climate change is likely to be a complex set of shifts in rainfall and temperature that may have annual, seasonal, and cumulative components, we propose that lakes may provide a sensitive integrator of hydrologic effects of climate change. Prolonged climate shifts such as drought alter water balance and the pathways and transport of water and solutes, generating strong chemical signals. For example, drier and warmer periods disconnect lakes from their catchments and from local groundwater flowpaths, altering transport of substances such as dissolved organic carbon from adjacent wetlands (Magnuson et al. 1997; Schindler 1997). In addition, during drought lakes often have higher concentrations of more conservative solutes, reflecting increases in evaporation over precipitation and lower lake water levels (Webster et al. 1996; 2000). This response can be complicated in extreme cases where drought is sufficient to reverse groundwater inputs and cause decreased in-lake ion concentrations (Webster et al. 1990).

Landscape position (the position of a lake along a local hydrologic flowpath) can influence the nature of chemical responses to climatic forcing. Lakes located high in the landscape, near groundwater and surface water divides are subject to more transience in local flowpaths of groundwater and greater variability in lake water levels as climate shifts (Anderson and Cheng 1993; Cheng and Anderson 1994; Winter 1999). The hydrologic budgets of seepage lakes located high in the landscape are dominated by precipitation, evaporation, and groundwater since surface water inlets and outlets are lacking. In these lakes changes in solutes during climate shifts are a function of the relative importance of evaporative losses and groundwater inputs. This close integration between climate and hydrology make seepage lakes sensitive indicators of climate change (Winter and Rosenberry 1998; Fritz 1996).

In this study we are evaluating chemical indicators for their potential to reflect shifts in hydrologic connections between lakes and (1) groundwater inputs and (2) wetlands. We expect to find that seepage lakes located higher in the landscape, with weaker connections to groundwater flow systems are responsive to climate and thus are more sensitive indicators of climate change. Because the lakes we consider most sensitive to climate are also those most sensitive to acid deposition, examination of temporal patterns in regions of different acid loading will provide us with more ability to separate acid rain and climate driven trends. This comparison will be facilitated through access to long-term data on the chemistry of seepage lakes in Wisconsin, a region subject to lower acid-loading rates compared to Maine.

We have three general objectives for this research project:

- Determine if changes in the chemistry of seepage lakes in Maine reflect climatic shifts over the past two decades.
  - ~ Determine if chemical responses differ among lake classes defined by the degree of hydrologic connection with the groundwater system and with wetlands.
  - ~ Compare chemical responses of Maine lakes with drought-induced changes in water chemistry observed for similar seepage lakes in Wisconsin.

- ~ Interpret responses to climate in the context of decreased acid deposition over the past 20 years
- Evaluate the sensitivity of seepage lake chemistry as an indicator of climate change in Maine.
- Recommend a research program to monitor lakes for climate change in the future and to identify impacts of concern to the health of lakes and availability of water resources in the state.

In addition to these primary objectives, this study will provide basic data to increase our understanding of the ecological responses of lakes to climate. Climate change has the potential to alter physical and chemical features of lakes in ways that could dramatically change community structure of aquatic organisms and ecosystem processes. We need better information on how climate influences lake ecosystems in order to understand multiple effects of regional disturbances such as acid rain, UV radiation, and land use alteration. Placing results of both short and long-term studies in a context of climate variability greatly improves our ability to make informed decisions on policy and management actions that affect lake ecosystems.

Methodology:

Water chemistry data on about 120 seepage lakes in Maine were collected in the mid-1980's and the late-1990's as part of earlier surveys. We selected a subset of 66 seepage lakes for re-sampling for this study. These lakes all have an ANC less than 100 μeq/L, our operational definition of lakes with low groundwater influence. Lakes were then allocated to classes defined by silica (low: < 0.1 mg/L and high: > 0.1 mg/L) and DOC (low, mid, high) (Figure 1). Silica was used to characterize the level of groundwater influence (Kahl et al. 1991) while DOC classes reflected the degree of wetland influence. A set of 35 seepage lakes in northern Wisconsin were classified in the same way; these lakes were sampled annually between 1987 and 2000. The Maine and Wisconsin lakes were part of the same EPA program (Long Term Monitoring), so the data are comparable in field and analytical methods.

Graduate research assistant Emily Seger sampled the 66 Maine lakes in fall 2001 and will sample them again during fall 2002. Chemical variables measured from the lakes included base cations, acid anions, DOC, true color, silica, conductance, pH, and alkalinity. All chemical analyses were performed at the Environmental Chemistry Lab at the University of Maine.

During the summer of 2002, we will develop metrics for lake classification by wetland connection and landscape position that are independent of lake chemistry. For wetland connection, we will quantify the area of wetlands adjacent to each study lake from vegetation maps. Relative lake position within the local flow system will be derived from U.S. Geologic Survey maps using information on lake elevation and distance to regional discharge points.

When lake sampling and chemical analysis are completed in winter 2003, we will relate changes in the major ion chemistry to climate variables such as precipitation and air temperature. Precipitation data were compiled from National Climate Data Center monitoring stations near locations of seepage lakes in Maine (Augusta Airport, Portland Jetport, and Grand Lake Stream) and Wisconsin (Minocqua Dam). The contrast between Maine and Wisconsin in historic trends in acid loading rates, will allow us to make more informed distinctions between patterns related to acid deposition and climate.

Principal Findings and Significance:

The field sampling data for the Maine lakes corresponded to periods of (1) dry to normal in 1986-87; (2) variable, near normal in the late 1990's and (3) the lowest precipitation year on record in 2001 (Figure 2). In spring to summer 2002 above normal precipitation reversed much of this drought although groundwater levels remain somewhat below normal. In Wisconsin, the most notable climatic event was a severe drought from 1987 to 1990 (Figure 3).

Preliminary analyses have focused on the two chemical constituents we proposed as indicators of flowpath shifts due to climate change (Figures 4-7). We assume that (1) dissolved organic carbon (DOC) levels reflect changes in wetland-lake connections and (2) changes in silica concentration reflect shifts in groundwater-lake interactions. We found that during dry periods, DOC and silica levels decreased in many Maine and Wisconsin seepage lakes, suggesting that even short-term climate shifts impact flowpath connections to these lakes and thus, their chemical environments. Patterns were more consistent across all lake hydrologic classes in Maine, while Wisconsin had stronger trends in the high DOC and silica level classes (more hydrologically connected classes).

While the data show a general trend in chemical response to drought, no particular class of lakes was consistently more responsive, and not all lakes within a class responded the same way. Perhaps a driver other than climate is affecting chemical indicators, or hydrologic classes based on the chemical constituents themselves inaccurately characterize lake types in terms of their landscape position and connection. To examine this latter possibility, other classification systems will be investigated during summer 2002. However, there is support in this preliminary examination that the chemistry of seepage lakes could be useful as a less complex indicator of hydrologic shifts due to climate change. We also plan to evaluate temporal patterns in other lake constituents for their potential as indicators of changes in hydrologic pathways.

Climate warming is a major issue for humankind globally, but the response and adaptation to climate change will occur locally. Our research addresses needs for information on the effects of climate change on aquatic ecosystems in Maine by evaluating an integrator of climate that does not rely entirely on statistical interpretations of weather variables. Use of the chemistry and hydrology of seepage lakes as early warning indicators, if successful, will provide a method for understanding the direction(s) of change in Maine's climate, and provide expectations of future impacts on water resources. Our research also addresses the need to conduct research that recognizes the impacts of multiple stressors such as acid deposition and climate change on aquatic ecosystems (Moore et al. 1997).

References:

Anderson, M.P. and X. Cheng. 1993. *J. Hydrol.* 145:1-18.

Cheng, X. and M.P. Anderson. 1994. *Water Resources Res.* 30:2041-2049.

Fritz, S.C. 1996. *Limnol. Oceanogr.* 41:882-889.

Kahl, J.S., S.A. Norton, C.S. Cronan, I.J. Fernandez, T.A. Haines, and L.C. Bacon, 1991. Chemical relationships of surface water chemistry and acidic deposition in Maine. Chapter 7 in: Regional Case Studies: Acid Deposition and Aquatic Ecosystems, D. Charles, ed., Springer-Verlag. NY.

Magnuson, J.J., K.E. Webster, R.A. Assel, C.J. Bowser, P.J. Dillon, J.G. Eaton, H.E. Evans, E.J. Fee, R.I. Hall, L.R. Mortsch, F.H. Quinn and D.W. Schindler. 1997. *Hydrol. Pro*c. 11:825-872.

Moore, M.V., M.L. Pace, J.R. Mather, P.S. Murdoch, R.W. Howarth, C.L. Folt, C.Y. Chen, H.F. Hemond, P.A. Flebbe, and C.T. Driscoll. 1997. *Hydrol. Pro*c. 11:925-948.

Schindler, D.W. 1997. *Hydrol. Proc.* 11:1043-1067.

Webster, K.E., T. Kratz, C. Bowser, J. Magnuson, and W. Rose. 1996. *Limnol. Oceanogr*. 41:977-984.

Webster, K.E., P.A. Soranno, S.B. Baines, T.K. Kratz, C.J. Bowser, P.J. Dillon, P. Campbell, E.J. Fee, and R.E. Hecky. 2000. *Freshwater Biology* 43:499-416.

Webster, K.E., A.D. Newell, L.A. Baker, and P.L. Brezonik. 1990. *Nature*. 347:374-376.
Winter, T.C. 1999. *Hydrogeology Journa*l. 7:28-45.
Winter, T.C. and D.O. Rosenberry. 1998. *Clim. Change* 40:189-209.

DOC Concentrations	**Silica Concentrations** Low (< = .1mg/L)	High (> .1 mg/L)
Low (<= 3 mg/L)	*ME = 19 lakes* *WI = 12 lakes*	*ME = 16 lakes* *WI = 0 lakes*
Mid (3 < 7 mg/L)	*ME = 11lakes* *WI = 17 lakes*	*ME = 7 lakes* *WI = 4 lakes*
High (>= 7 mg/L)	*ME = 7 lakes* *WI = 0 lake*	*ME = 6 lakes* *WI = 2 lakes*

Figure 1. Responses to climate shifts were tracked by lake class. Classes were determined by silica and DOC concentrations from 1986/87, the beginning year of each dataset.

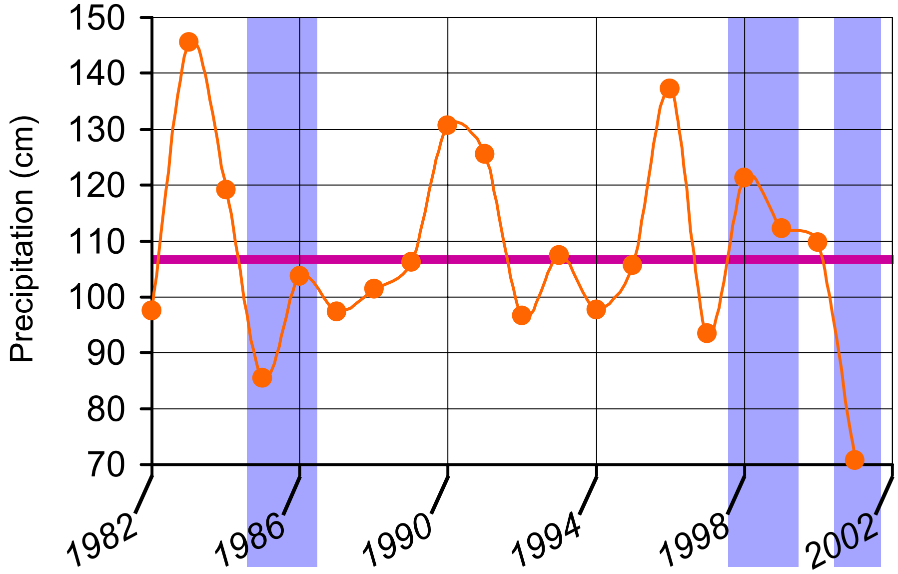


Figure 2. Maine total annual precipitation averaged over three Maine NCDC Stations. NCDC thirty year normal precipitation mean = 107.2 cm (indicated by purple line). A pattern of low to recovery, to above normal, to severely low precipitation occurred during years with data.

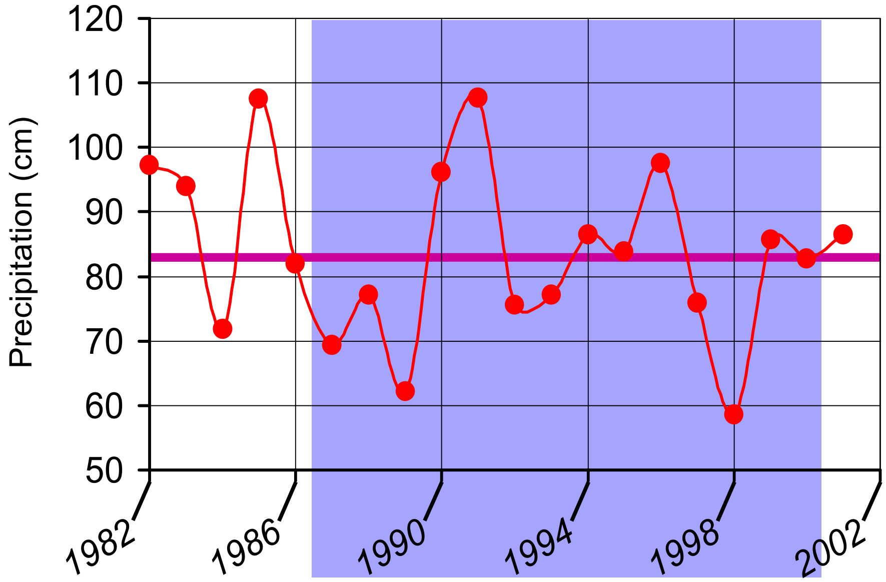
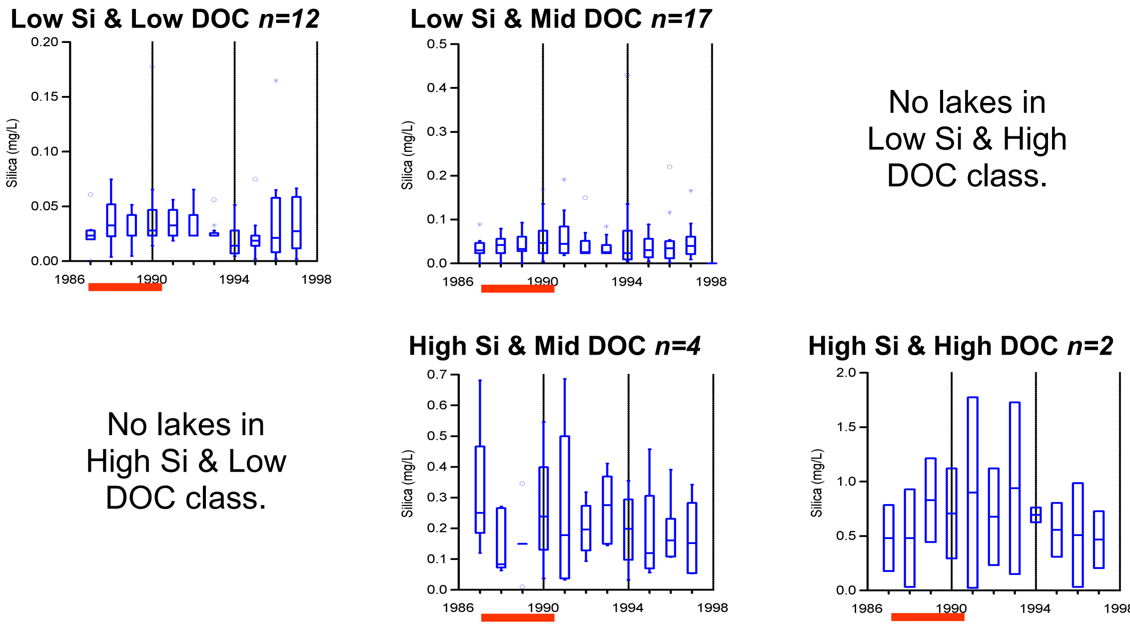


Figure 3. Wisconsin total annual precipitation at Minocqua Dam NCDC station. Shaded areas indicate years with lake data. NCDC thirty year normal precipitation mean = 82.9 cm (indicated by purple line). A severe drought occurred from 1987 to 1990, followed by a transition to above/normal precipitation.

Wisconsin Silica Trends Grouped by Lake Class. *Figure 4*

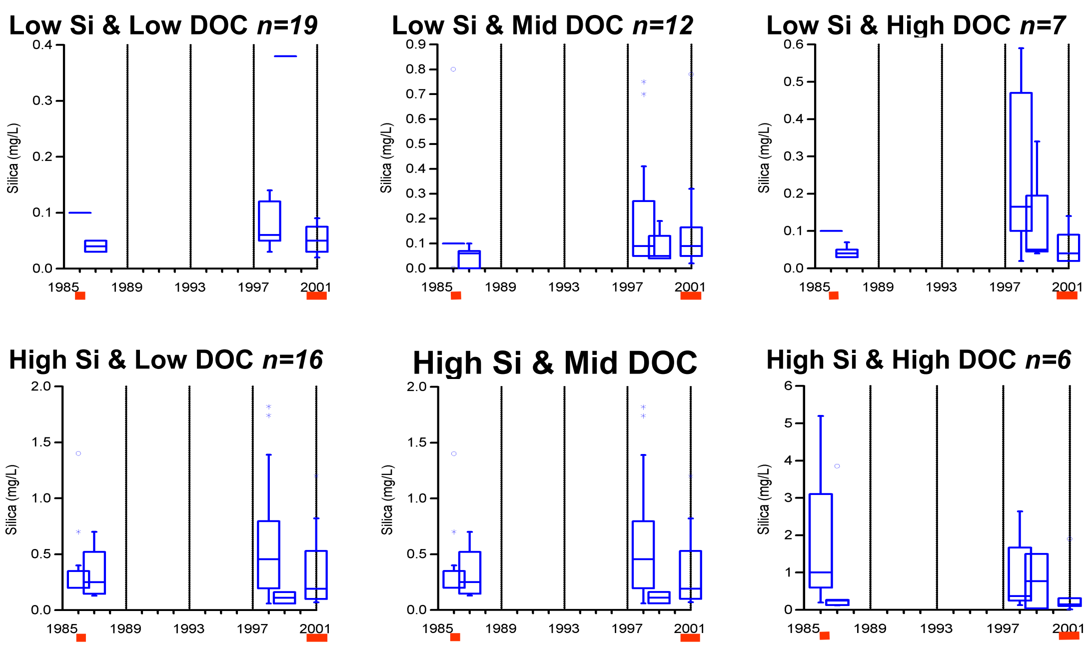
Indicates drought years. See Figures 2 & 3



A few lakes had silica decreases during drought years, yet there were no apparent trends. However, lower silica classes had a general decrease in the slightly dry mid-90s.

Maine Silica Trends Grouped by Lake Class. *Figure 5*

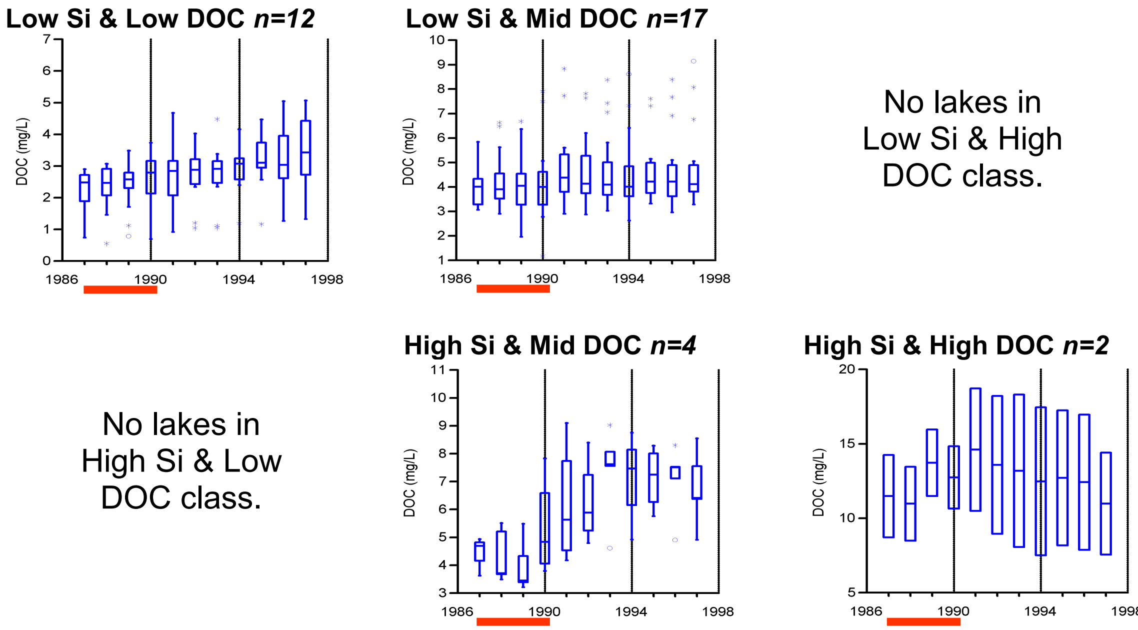
Indicates drought years. See Fig. 2 & 3.



More apparent trends occurred in Maine. Both high and low silica classes had decreases in concentrations during dry years.

Wisconsin DOC Trends Grouped by Lake Class. ***Figure 6***

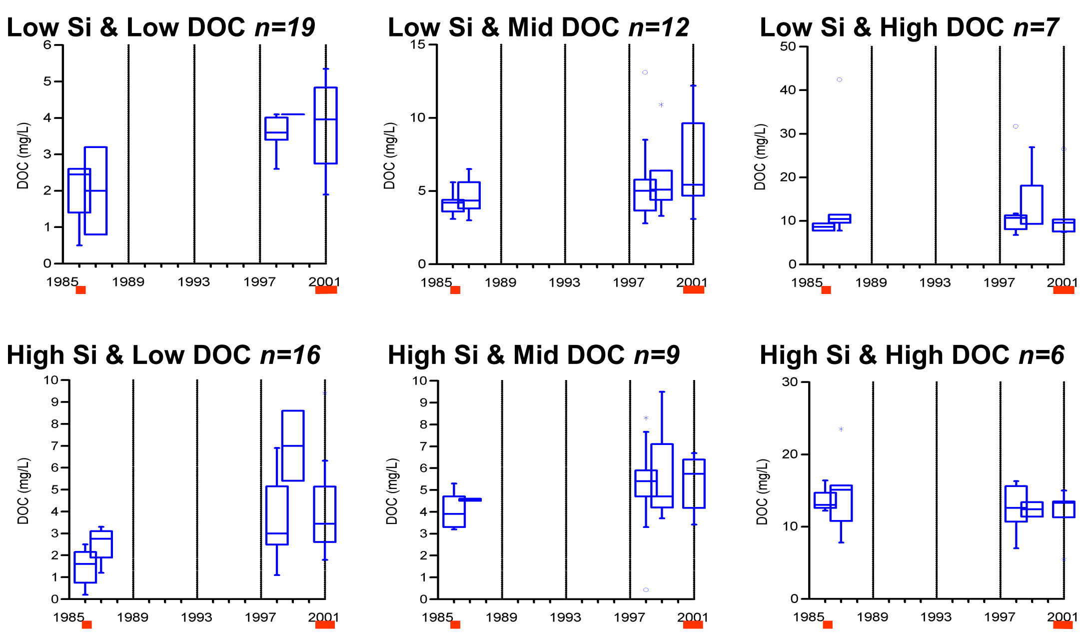
Indicates drought years. See Figures 2 & 3



DOC decreased in some lakes of the lower DOC classes during later drought years, with increases or steady levels in recovery years. High DOC lakes were more variable.

Maine DOC Trends Grouped by Lake Class. ***Figure 7***

Indicates drought years. See Fig. 2 & 3.



All classes had a general increase in DOC during the first dry-to-recovery period. Yet in the later drought, higher classes and some lakes in class 1 had a decrease in DOC.